Reply to "Comment on acp-2021-329"

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We are grateful to Bernd Kärcher for his comment and his suggestions on how to further improve the model-based estimates of the aviation soot-cirrus effect.

We are fully aware of the limitations related to the representation of the ice formation processes in our model (and in global models in general) and of the uncertainties connected with that. These are clearly mentioned and discussed in our study and are exactly the motivation for it. This is stated already in the title: *Exploring the uncertainties of the aviation soot-cirrus effect*. So, this paper is not simply *"the latest attempt to arrive at a GCM-based solution"*, as stated in Bernd Kärcher's comment, but it is a detailed analysis of which role the aforementioned limitations and uncertainties play in the quantification of the resulting radiative forcing. This is explicitly written in the introduction: "*Rather than attempting to provide a single estimate of the aviation soot-cirrus effect, the goal of this study is to explore the uncertainties related to the microphysical and dynamic aspects of this effect, in order to provide a realistic, albeit broad, range of possible values for the resulting climate impact."* (lines 87-91). We also note that GCMs (or global models in general) are the only available tools to provide global quantifications of the radiative forcing resulting from this effect.

The comment seems to suggest that wrong parameters were chosen to drive the cirrus parametrization in this study (*"…I recommend using more appropriate estimations of both, activated fraction and nucleation threshold. The former happens to be greatly overestimated while the latter is underestimated in the present study."*). This is however not completely correct: as clearly shown in Fig. 1, we did not choose single values for these parameters, but we performed many model experiments to cover a wide range of measured values, for both the active fraction (f_{act}) and the nucleation threshold (S_{crit}), resulting in 9 different pairs for these two parameters. We also consciously included parameter combinations which might somewhat be less realistic, in order to directly compare with previous model studies where such values were adopted. We further note that the parameters deemed as "appropriate" by Bernd Kärcher in his comment and in his recent study (Kärcher et al., 2021) are fully covered by our analysis (f_{act}<1% and S_{crit}=1.4, i.e., close to the homogeneous freezing limit, see Fig. 1). Choosing larger values for S_{crit} (e.g., S_{crit}=1.5) would very likely lead to results lacking any statistical significance. Hence, we refrained from using such values, also to avoid wasting large computing resources, which are required to perform such climate model simulations.

In spite of its known limitations, the cirrus parametrization adopted in our model (Kärcher et al., 2006) is operationally included in several other climate models and has been evaluated and applied in many peer-reviewed studies of the last 10 years (Hendricks et al., 2011; Kuebbeler et al. 2014; Gasparini and Lohmann, 2016; Gasparini et al., 2017; Penner et al., 2018; Righi et al., 2020; Gasparini et al., 2020; Lohmann et al., 2020). It therefore represents the state-of-the-art of global modelling of cirrus clouds. The applicability of this parametrization for the purpose of our study has been demonstrated in a very detailed model description and evaluation paper on the EMAC-MADE3 model (Righi et al., 2020).

Climate models, in many cases, need to deal with simplified representations of processes, in order to be applicable to the large spatial and temporal scales. This is a necessary compromise in order to describe aerosol-cloud-climate interactions on the global scale and to come up with a quantification of the resulting climate forcing (in this case, of the aviation-soot cirrus effect). We are grateful to Bernd Kärcher and his co-authors for their recent advancements in the microphysical description of the underlying effect (Kärcher et al., 2021; Marcolli et al., 2021) and we agree that they should be considered for implementation in future model studies. However, the implementation of new processes in a global climate model requires considerable efforts. This is especially the case when aerosol-cloud interaction processes are involved, since this requires a new tuning of the model, which is usually computationally expensive, and a re-evaluation of the whole system. Before further increasing the model complexity, it is therefore important to show whether the processes under consideration lead to relevant climate impacts. This is precisely the goal of our study, which can also serve as a basis of future, more refined studies, should some missing processes turn out to be relevant for the aviation effect under investigation.

As mentioned above, another goal of our paper is to directly compare with existing model-based quantifications of the aviation soot-cirrus climate effect, which in several cases reported very large radiative forcing values, as also criticized in the Kärcher et al. (2021) study. Part of the parameter space explored in our sensitivity simulations cover indeed the assumptions done in such studies, but nevertheless we were not able to confirm the large radiative forcing values reported there (see Sect. 5, second paragraph, lines 521-536). Hence, our conclusions are very much aligned to the conclusions of Kärcher et al. (2021), i.e., that in many of the existing model-based quantifications, the global radiative forcing effect via aviation-soot cirrus interactions may be overestimated.

In the revised version of our manuscript we have considered Bernd Kärcher's comments and the perspectives offered by the new studies he mentions. The following paragraphs have been added in different sections:

- **Sect. 3**: *"…which implies that only a very low fraction of aviation soot can effectively be active as INPs in the upper troposphere. This was also the conclusion by Kärcher et al. (2021): In a recent process-oriented analysis using a high-resolution column model based on the parametrization by Marcolli et al. (2021), they suggested that less than 1% of aviation soot particles can lead to the formation of ice crystals in competition with homogenous freezing."*
- **Sect. 4.2**: *"Kärcher et al. (2021) also argued against large RF effects from aviation soot-cirrus interactions, pointing to the limitations of global models in representing key processes as a possible reason for overestimated effects."*
- **Sect. 5 (Conclusions)**: *"Recent advancements in the representation of key microphysical processes for the investigated effects (Kärcher et al., 2021; Marcolli et al., 2021) should also be considered for implementation in global models. […] Moreover, the cirrus parametrization by Kärcher et al. (2006) implemented in EMAC-MADE3 has some known limitations which should be addressed in future versions of the model, for example replacing critical supersaturation with an activation spectrum following the change in the active INP population with increasing supersaturation and considering the effects of particle size and coating on the soot nucleation process."*

We believe that this kind of discussions greatly helps the scientific progress on a highly debated subject and we are grateful to ACP for the opportunity of publicly hosting these contributions.

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